Gilbert Ford Kinney

THE EFFECT OF A COMPOSITE ATMOSPHERE ON RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION.

UNITED STATES
NAVAL POSTGRADUATE SCHOOL

THE EFFECT OF A COMPOSITE ATMOSPHERE ON RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION

By

G. F. Kinney
Professor of Chemical Engineering

RESEARCH PAPER NO. 9

October 1956

THE EFFECT OF A COMPOSITE ATMOSPHERE ON RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION

by

ilbert ord
G. F. KINNEY
Professor of Chemical Engineering

Research Paper No. 9
UNITED STATES NAVAL POSTGRADUATE SCHOOL
October 1956

THE EFFECT OF A COMPOSITE ATMOSPHERE ON RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION

Thermal radiation effects accompanying a nuclear weapon detonation have been described in some detail (1.2). It has been indicated that the damaging effects of thermal radiation are to be correlated with total radiant energy received per unit area, and that within limits are not greatly dependent on the rate of reception.

A quantitative relation between radiant exposure (Q) at a distance (D) and the total radiant energy emitted (E) is provided by equation 6.35.1 of reference (1).

$$Q = \frac{E}{4\pi D^2} e^{-kD} \qquad (1)$$

The total radiant energy is assigned a value of 6.7×10^{12} calories for a nominal (20KT) atomic bomb.

The term e^{-kD} of this equation represents numerically the transmission of the atmosphere (here assumed uniform). It is a correction for the atmospheric attenuation caused primarily by a scattering out from a direct beam, although with smog or smoky haze absorption may also contribute. The scattering in of indirect radiation and the effects of multiple scattering are neglected). Item (k) of the equation is called the attenuation coefficient, extinction coefficient, or, less appropriately, the absorption coefficient. Its value is a function of wave length, as evidenced for example by the changing colors of the setting sun. However

33616

this variation is not large in magnitude and the atmosphere may be assigned average values that apply for the wave length range 0-10μ (reference 3). Coefficient (k) has the units of reciprocal length, making the product (kD) a dimensionless ratio. This ratio has been identified as the optical thickness of the (uniform) atmosphere.

A composite atmosphere is characterized by a variety of attenuation with different coefficients (k_1, k_2, ...), each effective over paths with distances (d_1, d_2, ...). Here more than one transmission term of the form e^{-kd} is required. Adapting equation (1) to provide for this, and also converting into working units,

$$Q = \frac{575\, n}{(D')^2} \left(e^{-k_1 d_1} \cdot e^{-k_2 d_2} \cdots \right) \qquad (2)$$

where D' = slant range (total distance) in thousands of feet, and equals ($d_1 + d_2 + \ldots$)

d_1, d_2 = lengths of paths characterized by attenuation coefficients k_1, k_2, with units such that the optical thickness (kd product) is without units.

k_1, k_2 = attenuation coefficients

n = energy yield in terms of a nominal (20KT) atomic burst.

A mean attenuation coefficient (k') for a composite atmosphere may defined so that the results of simpler equation (1) conform with those obtained from equation (2). That is,

$$k' = k_1(d_1/D) + k_2(d_2/D + \ldots) \qquad (3)$$

each coefficient for portions of a composite path being weighted in accordance with its fractional path length. For a continuum the corresponding form is

$$k' = (1/D)\int_0^D k \, d(D) \qquad (4)$$

indicated integration, if necessary, may be performed graphically a plot of k vs distance. From these relations it follows that a n attenuation coefficient based on an average visibility distance not be representative of a composite atmosphere.

The relation of equation (2) is conveniently utilized if expressed a logarithmic or a decibel form. Taking logarithms to base 10,

$$\log_{10} Q = 2.579 + \log n - 2 \log D' - \frac{1}{2.303}(k_1 d_1 + k_2 d_2 + \ldots) \quad (5)$$

re Q = radiant exposure, calories per square centimeter
n = size of burst, in units of 20KT
D' = slant range, thousands of feet

this relation the kd items have become additive terms. It also can noted that items of the form $kd/(2.303)$ correspond to an optical density, $\log_{10}(I/I_0)$, but for thermal radiation, and likewise are convenient additive terms.

nomographic solution for relation (5) is presented in figure I, with on yield expressed in terms of equivalent tons of TNT and the slant e in feet. Entry to the nomograph is ordinarily at a given yield slant range. A line through these points to the Q' scale gives a e for radiant exposure without attenuation. Attenuation is prod for by extending a line from the Q' scale through the pertinent e of kd(total for all parts of the path) to the scale for Q. Or rnatively, allowance is made for the attenuation in one portion of path length by using a kd value for that portion. For additional nuation in other path lengths transfer is made back to the Q' scale ugh the zero point of the kd scale, providing identical values on the d the Q' scales. A line from the new point on the Q' scale through new kd to the Q scale is made as before. Note that the Q and Q' es are symmetrical about the zero point of the kd scale.

Attenuation coefficients for various paths may be estimated from visibility distances (3). Figure 2 gives the International Visibility Code Indices for various visibility distances, and provides corresponding k values per kilometer and per nautical mile. One nautical mile is 1.853 kilometers, and for these purposes may be taken as 6000 feet. The k valu of 0.014 per kilometer (0.026) per nautical mile) represents a lower limi value for "pure" air at standard density. There is also some sort of uppe limit of applicability for purposes of estimating radiant exposure throug fog or smog, for any effect of "scattering in" is ignored here.

To make the results obtained from these relations meaningful some estimate of the possible damage that might be inflicted is needed. Figure 3 provides a condensed summary of selected information of this type as given in reference (1). Also provided are approximate threshold values for the destruction of a dark grey cellulose material (actually a paper stock) for a variety of thicknesses (4).

ACKNOWLEDGMENT

A nomograph on which figure (1) is based was prepared during the school year 1954-55 as a class project by members of the RW2 section:

LT. Thomas J. Murphy, Jr., USN
LT. Maurice A. Horn, USN
LT. Richard C. Branton, USN
LT. Thomas D. Pfundstein, USN

Their interest and effort are responsible for this report.

The threshold energy values of figure (4) were reviewed by Mr. S.B. Martin of the U.S. Naval Radiological Defense Laboratory. The nomograph of figure (1) was reviewed by Dr. W.B. Plum of the same laboratory. Their assistance is gratefully acknowledged.

REFERENCES

1. Effects of Atomic Weapons, Combat Forces Press, 1950
2. AFSWP-700
3. The atmospheres of the Earth and Planets, 2nd edition. Edited by Gerard P. Kuiper; Chapter III, Scattering in the Atmospheres of the Earth and Planets, H.C. van de Hulst. University of Chicago Press, 1951.
4. S.B. Martin, private communication

SYMBOLS

D Total distance

D' Slant range, thousands of feet

d Path distance

E Total radiant energy

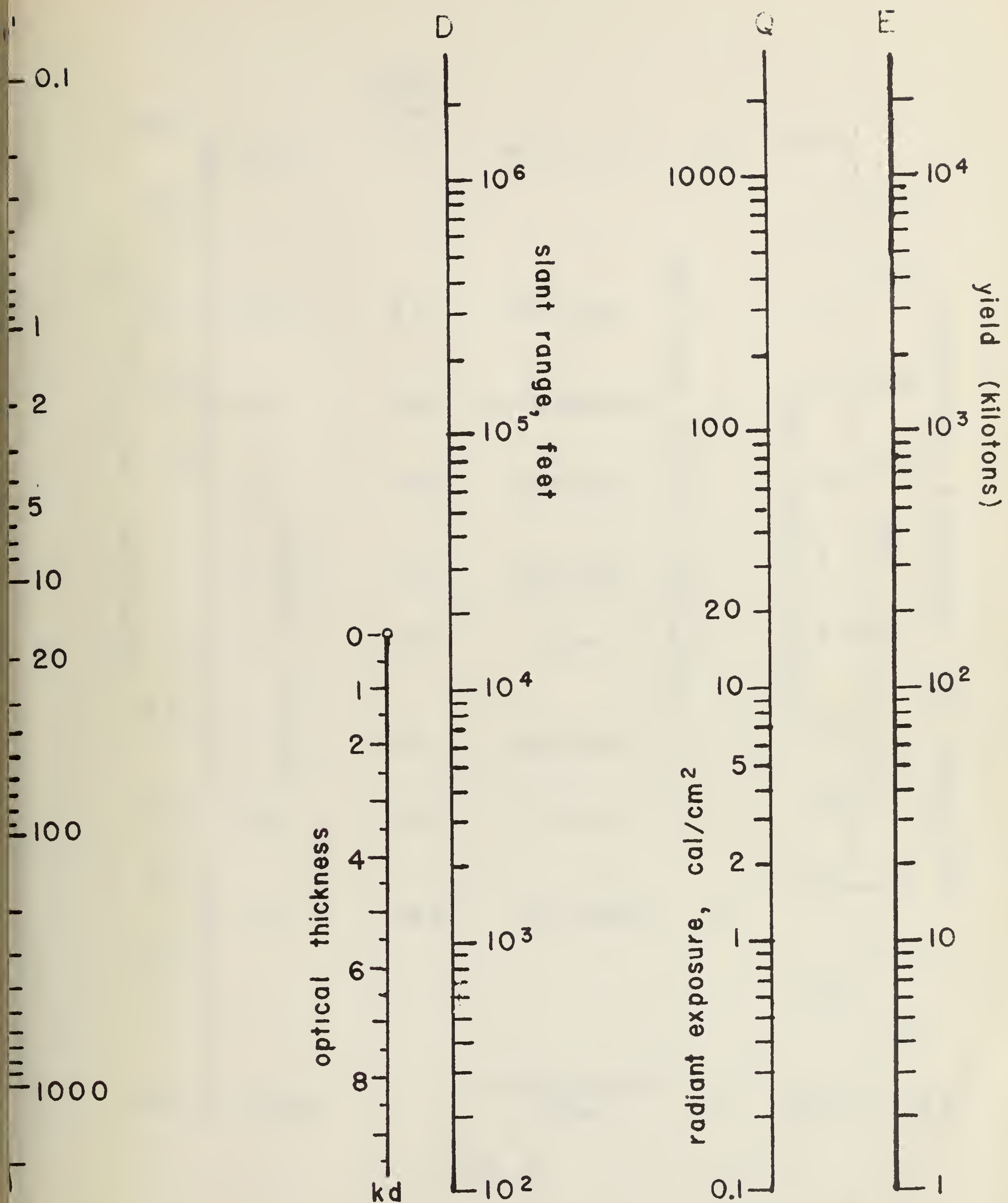
k Attenuation coefficient in units of reciprocal length consistent with those of path length d.

k' Mean attenuation coefficient for a composite path

n Energy release in terms of nominal (20 KT) weapon

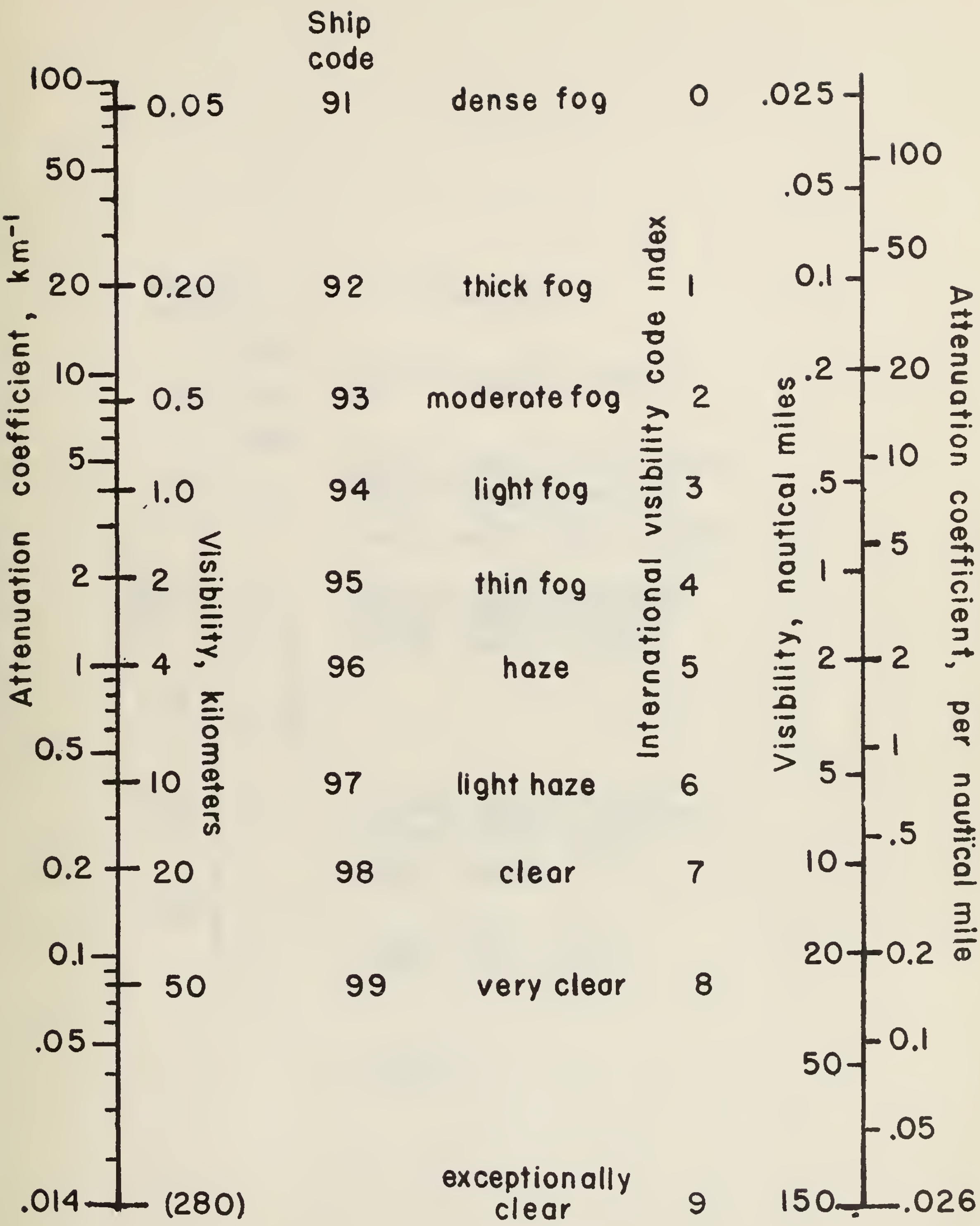
Q Radiant exposure, calories per square centimeter

Q' Radiant exposure before allowance for attenuation



0.1
1
2
5
10
20
100
1000
D
slant range, feet
10^6
10^5
10^4
10^3
10^2
optical thickness
0
1
2
4
6
8
kd
Q
radiant exposure, cal/cm^2
1000
100
20
10
5
2
1
0.1
E
yield (kilotons)
10^4
10^3
10^2
10
1

Fig. 1



Ship code
Attenuation coefficient, km⁻¹
Visibility, kilometers
International visibility code index
Visibility, nautical miles
Attenuation coefficient, per nautical mile
100
50
20
10
5
2
1
0.5
0.2
0.1
.05
.014
0.05
0.20
0.5
1.0
2
4
10
20
50
(280)
91 dense fog 0
92 thick fog 1
93 moderate fog 2
94 light fog 3
95 thin fog 4
96 haze 5
97 light haze 6
98 clear 7
99 very clear 8
exceptionally clear 9
.025
.05
0.1
.2
.5
1
2
5
10
20
50
150
100
50
20
10
5
2
1
.5
0.2
0.1
.05
.026

Fig. 2

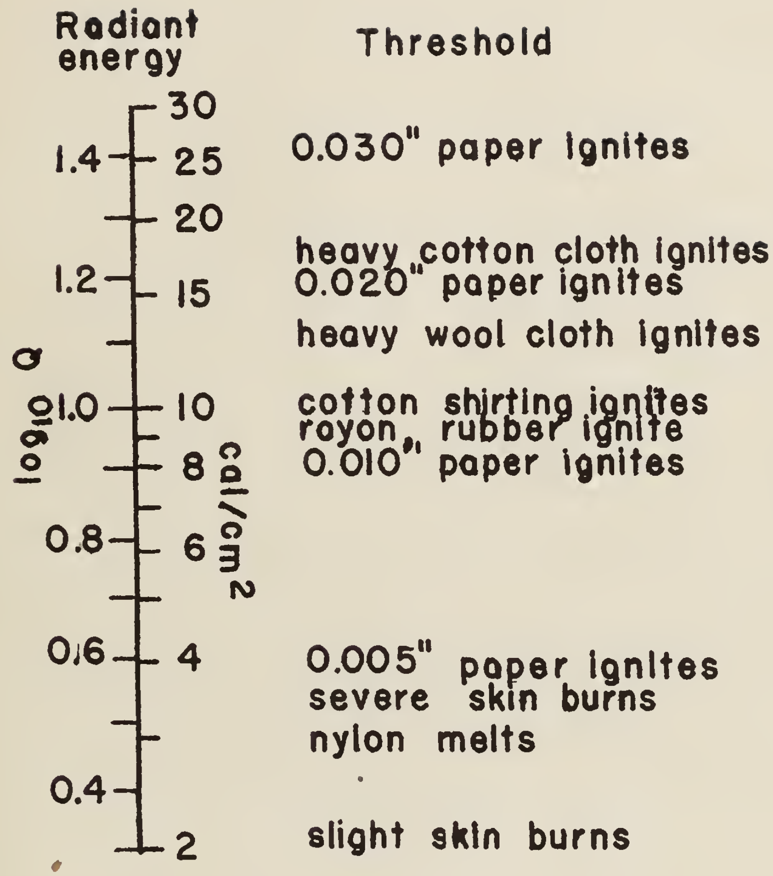

Radiant energy
Threshold
30
1.4
25
0.030" paper ignites
20
heavy cotton cloth ignites
1.2
15
0.020" paper ignites
heavy wool cloth ignites
$\log_{10} Q$
1.0
10
cotton shirting ignites
rayon, rubber ignite
8
0.010" paper ignites
cal/cm^2
0.8
6
0.6
4
0.005" paper ignites
severe skin burns
nylon melts
0.4
2
slight skin burns

Fig. 3